NASA-CR-190680

MCAT Institute
Progress Report
92-014

Ames
116446
P-25

HYPERSONIC CODE EFFICIENCY AND VALIDATION STUDIES

Bradford C. Bennett

(NASA-CR-190680) HYPERSONIC CODE EFFICIENCY AND VALIDATION STUDIES Progress Report (MCAT Inst.) 25 p

N92-31533

Unclas

G3/02 0116446

August 1992

NCC2-522

MCAT Institute
3933 Blue Gum Drive
San Jose, CA 95127

MCAT Institute
Progress Report
92-014

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

HYPERSONIC CODE EFFICIENCY AND VALIDATION STUDIES

Bradford C. Bennett

August 1992

NCC2-522

MCAT Institute
3933 Blue Gum Drive
San Jose, CA 95127

HYPERSONIC CODE EFFICIENCY AND VALIDATION STUDIES

Bradford C. Bennett

Introduction

Renewed interest in hypersonic and supersonic flows spurred the development of the Compressible Navier-Stokes (CNS) code.[1] Originally developed for external flows, CNS was modified to enable it to also be applied to internal high speed flows.[2] In the initial phase of this study CNS was applied to both internal and external flow applications and fellow researchers were taught to run CNS.

The second phase of this research was the development of surface grids over various aircraft configurations for the High Speed Research Program (HSRP). The complex nature of these configurations required the development of improved surface grid generation techniques. A significant portion of the grid generation effort was devoted to testing and recommending modifications to early versions of the S3D surface grid generation code.[3]

CNS CALCULATIONS

Mach 5 Inlet

The experimental inlet is a scale model of a proposed Mach 5 aircraft mixed- break compression inlet, see Figure 1. The inlet, test conditions, and computational results are fully described in last year's annual report.[4] One drawback to these computations was that they were computationally expensive, requiring 30 hours of Cray YMP time, using the F3D algorithm in CNS. The source of the problem was found when free stream calculations, run as if they were internal flow, also diverged with moderate time steps. This indicated that there was a basic problem. Various grids were used to demonstrate that the problem was not in the grid. Intensive study and analysis revealed that the source of the problem was in the subroutine VISMATK. It was discovered that the indices of three matrices were inverted, thereby supplying incorrect data to the updating of the solution matrix. The correction of this coding error eliminated the problem and CNS was able to run the Mach 5 inlet flow with CFL numbers between 1.5 and 9.0. The result is an increase in speed of almost an order of magnitude over the previously stable time step size. Figure 2 shows the typical increase in convergence rate of the corrected code over the code with the mistake. It is important to note that the error in the subroutine VISMATK did not effect external flow calculations and even for internal flow calculations the results of the computation were unaffected. Only the rate of convergence of internal flow computations were affected by this error.

MODEL H CONFIGURATION

The McDonnell Douglas Model H configuration is shown in Figure 3. It is a complete configuration powered model of a hypersonic vehicle. The Applied Computational Branch, RFA, was asked to perform time-dependent calculations on the start-up flow of this model in a wind tunnel. This researcher was asked to perform these computations. A grid was generated and with the assistance of Chris Atwood the BLAST3D code[5] was applied to the unsteady start-up flow around the model. Unfortunately, the overpressures of the Mach 19 flow were too large for the code to handle. Next, the TUFF code[6] developed by Greg Molvik was tried. The TUFF code could not compute the "base" flow aft of the engine (power off) because it is an upwind scheme. Finally, the flow was calculated using the CNS code.

Test Conditions

The calculation was to model the start-up of a shock tube driven hypersonic wind tunnel. In such a wind tunnel the available test time is very short, because reflecting shock waves quickly disturb the flow. The calculation was performed to discover whether the flow would reach steady state in the alloted test time. Of special concern was the region just upstream of the engine exhaust.

The flow consisted of Mach 19 flow, with a total temperature of 5800^{o}R, a dynamic pressure of 0.95 psia, and a Reynolds' number of 400,000/ft. The engine exhaust flow was Mach 5.19 with a density almost 600 times that of the Mach 19 free stream flow.

Calculations and Results

Two-dimensional calculations were performed on the grid shown in Figure 4. The grid was generated with the VisualGrid[7] code and consists of 87 points along the model and 49 points away from the body. Since CNS is a fully three-dimensional code there were three planes of points in the third dimension to allow the code to run.

Three sets of calculations were performed. The first set of inviscid calculations demonstrated the ability of CNS to compute the flow. A second set of calculations were viscous and were initiated with Mach 19 flow over the entire flow domain. Figure 5 shows the Mach contours of this computation after the flow has reached steady state. There are two important results from this calculation. First, there was little flow separation upstream of the engine exhaust. Second, the flow achieved steady state in less than a third of a millisecond, significantly less time than the one millisecond of available test time. A third calculation had a more realistic initial condition. The calculation was started with an underexpanded Mach 5 flow out of the engine exhaust as well as the Mach 19 free stream flow. Results of this calculation are shown in Figures 6 and 7. Again there was no significant separation and the time to achieve steady state was about the same.

The results of these calculations were communicated to Mcdonnell Douglas engineers to aid in their wind tunnel test design.

GRID GENERATION

Boeing 1807 Model

Several surface grids were generated for the Boeing 1807configuration. The first grid generated used a grid created by Samson Cheung as input. This grid is shown in Figure 8. The grid, made up of a series of constant steamwise cuts (lines with constant x values), was generated for use with the UPS code. It is difficult to determine the trailing edge of the wing with this type of grid and after the wing there is a collapsed plane which allows the use of a constant number of points over the entire body. This type of grid requires too many points to be computationally desirable for use with a three-dimensional time marching code such as CNS.

The surface grid shown in Figure 9 was created using S3D from the input described above and an additional definition of the trailing edge. It divides the body into relatively few computational zones, but uses significantly less points than the original surface grid.

A second grid was generated from a different set of data describing the same configuration. The computed surface grid is shown in Figure 10. The interest in this definition is because the sharp break between the inboard subsonic (rounded leading edge) portion of the wing and the outboard supersonic (sharp leading edge) portion of the wing is maintained. Here there are more zones and breaking the supersonic portion of the wing into an outboard and inboard section complicates the generation of the computational grid.

It should be noted that this grid (and the grids described later in this report) were generated as S3D was being developed. Often features that were needed did not exist and Ray Luh, the main developer of S3D,and this researcher worked together to add the needed features. In addition, some features could not be added within the required time frame and additional codes were written to perform small, but necessary tasks.

Nonetheless, when using a surface grid generation code such as S3D, a great many more zones are created than the few shown in the two grids described above. Geometric zones are needed wherever there is a "break" in the geometry that needs to be preserved. Thus the top and the body of the wing are divided into different zones and if the wing/body intersect is to be preserved, the wing and body are divided. This procedure complicates the surface grid generation, but is unavoidable with the present technology. Figure 11 shows a typical intermediate grid with 26 zones (not all can be distinguished). After the grid is complete, the surface grid is reassembled into zones which are appropriate for volume grid generation.

As can be seen by the grids described in this report, the details, zonal boundaries, number of points, and many characteristics are determined by both the needs of the computational algorithm to be used for the calculation and the capabilities of the volume grid generator. In the above two cases, a great effort was made to create grids which would simplify the effort needed to generate the volume computational grids.

Boeing Hagland(911) Configuration

The Boeing Hagland (911) configuration is a supersonic transport designed to minimize sonic boom. Because a more complete analysis of this configuration was desired, a more complex model of the configuration was generated. Most notably the nacelles are included in the surface grids generated.

The first grid generated was used as input to a two-dimensional hyperbolic volume grid generation code. Thus, this grid had the limitation of constant streamwise cuts that were continuous around the entire vehicle. This greatly complicates the surface grid generation, but makes the volume grid generation quite simple. Various views of the resulting surface grid are shown in Figures 12 and 13. It consists of five zones, the minimum number possible with the given restrictions. The first zone includes the fuselage and wing up to the start of the first (upwind) nacelle. The second zone goes to the start of the second (downwind) nacelle. The third zone includes portions of both nacelles and ends at the end of the first nacelle. The forth zone goes to the end of the second nacelle. The fifth zone covers the rest of the vehicle. The surface grid contains almost 18,000 points. As can be seen in Figure 12, there is a collapsed plane of points following the trailing edge of the wing. (The shape of the wing can be clearly seen in Figure 14.) In the configuration shown, this grid was used with the UPS code. Overlaps in the surface grid are required to generate a volume grid with overlaps, which can be used with CNS. Overlaps were generated at the four interfaces of the surface zones. Other refinements to the surface grids were performed in coordination with the volume grid generation.

The second grid generated had four zones (excluding the nacelles).Three zones had constant streamwise cuts and the other was a polar grid over the tip of the wing, as shown in Figure 14. This grid was created to supply input into GRIDGEN, a volume grid generation code, in order to generate a volume grid for CNSFV (the finite volume version of CNS).

A final task involving the Hagland model was the conversion of an optimized geometry to a realistic geometry. This geometry was then put into a form that could be used to create NC machine input and delivered to code RAA so that a wind tunnel model could be manufactured.

Boeing Reference H Configuration

The Reference H geometry was obtained as a series of cross sections. This data was converted to a form which S3D could read. For this configuration, which includes both vertical and horizontal tails, this is not an appropriate organization of the surface data. New techniques were developed to put the data in a form so that S3D can create an appropriate grid. An appropriate surface grid has been partially completed. The incomplete surface grid is shown in Figure 15.

SUMMARY

This research effort had several significant contributions in this year. The CNS code was corrected so that the maximum stable time step size was increased an order of magnitude for internal flows. Calculations were performed which assisted in the design of a McDonnell Douglas hypersonic vehicle model. Finally, several surface grids were generated which were required by the HSRP optimization effort. An important component of the grid generation work involved working with the developer of S3D, Ray Luh, to develop useful options within S3D. This effort resulted in a code which has capabilities and features that are needed in realistic surface grid generation.

References

1. Ryan, J. S., Flores, J., and Chow, C.-Y., "Development and Validation of CNS (Compressible Navier-Stokes) for Hypersonic Applications," AIAA Paper 89-1839, June 12-14, 1989.

2. Bennett, B.C. and Edwards, T.A., "Calculation of Hypersonic Forebody/Inlet Flow Fields," AIAA Paper 90-1493, June 18-20, 1990.

3. Luh, Raymond Ching-Chung, Pierce, L.E., Yip, David, "Interactive Surface Grid Generation," AIAA Paper 91-0796, January 7-10, 1991.

4. Bennett, Bradford C., "Power-On Performance Predictions for a Complete Generic Hypersonic Vehicle Configuration," MCAT Institute, Annual Report 91-004, April 1991.

5. Atwood, Christopher A., "An Upwind Approach to Unsteady Flowfield Simulation," AIAA Paper 90-3100, August 20-22, 1990.

6. Molvik, G.A. and Merkle, C.L., "A Set of Strongly Coupled Upwind Algorithms for Computing Flows in Chemical Nonequilibrium," AIAA Paper 89-0199, January 9-12, 1989.

7. Cordova, J.Q. and Barth, T.J., "Grid Generation for General 2-D Regions Using Hyperbolic Equations," AIAA Paper 88-0520, January 11-14, 1988.

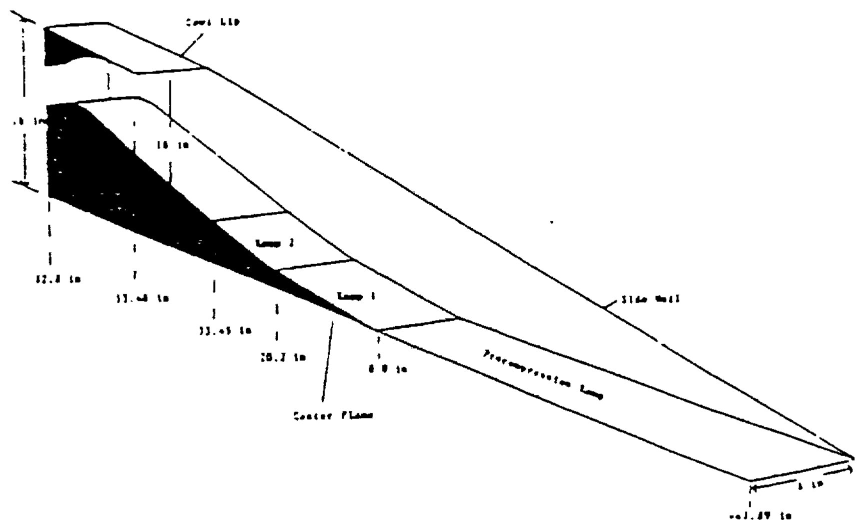
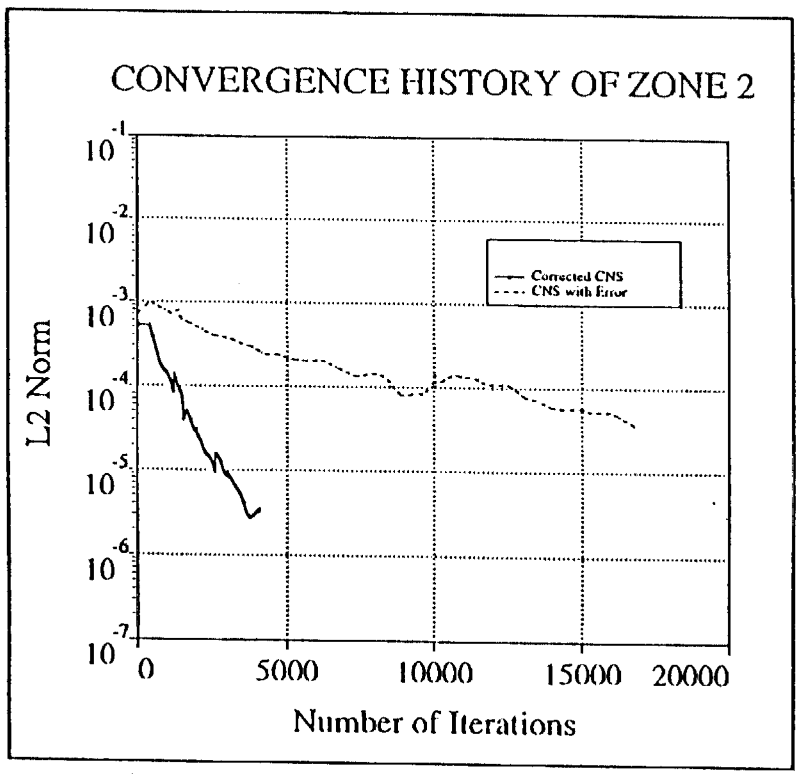


Figure 1. Schematic of Lewis Mach 5 inlet.

Figure 2. Comparison of convergence history of computation before and after correction of coding error in CNS of zone 2 of Mach 5 inlet calculation. inlet.



MODEL H CONFIGURATION (U)

FULL CONFIGURATION POWERED MODEL

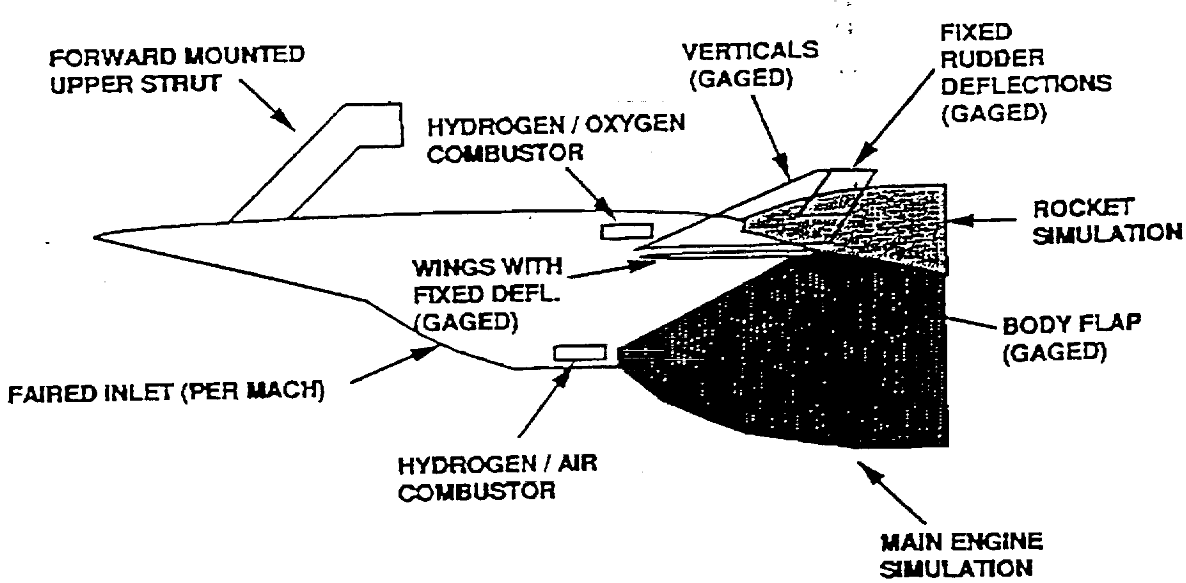
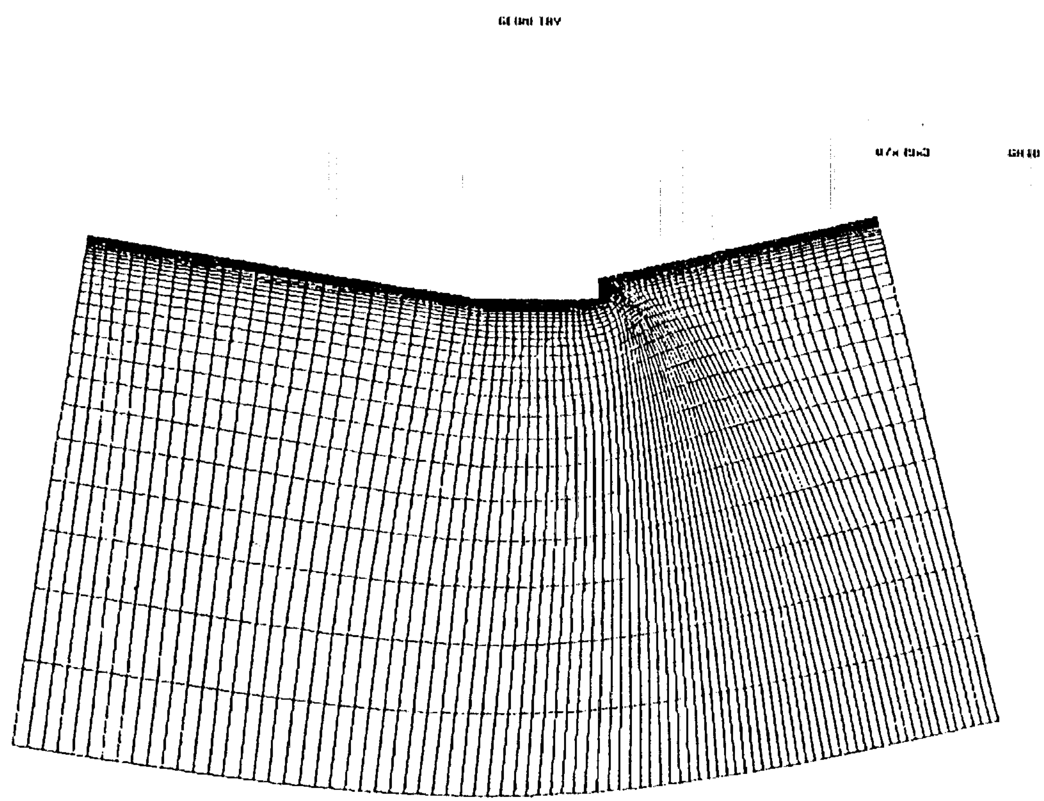
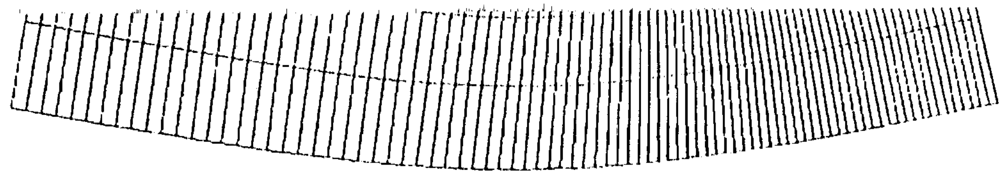


Figure 3

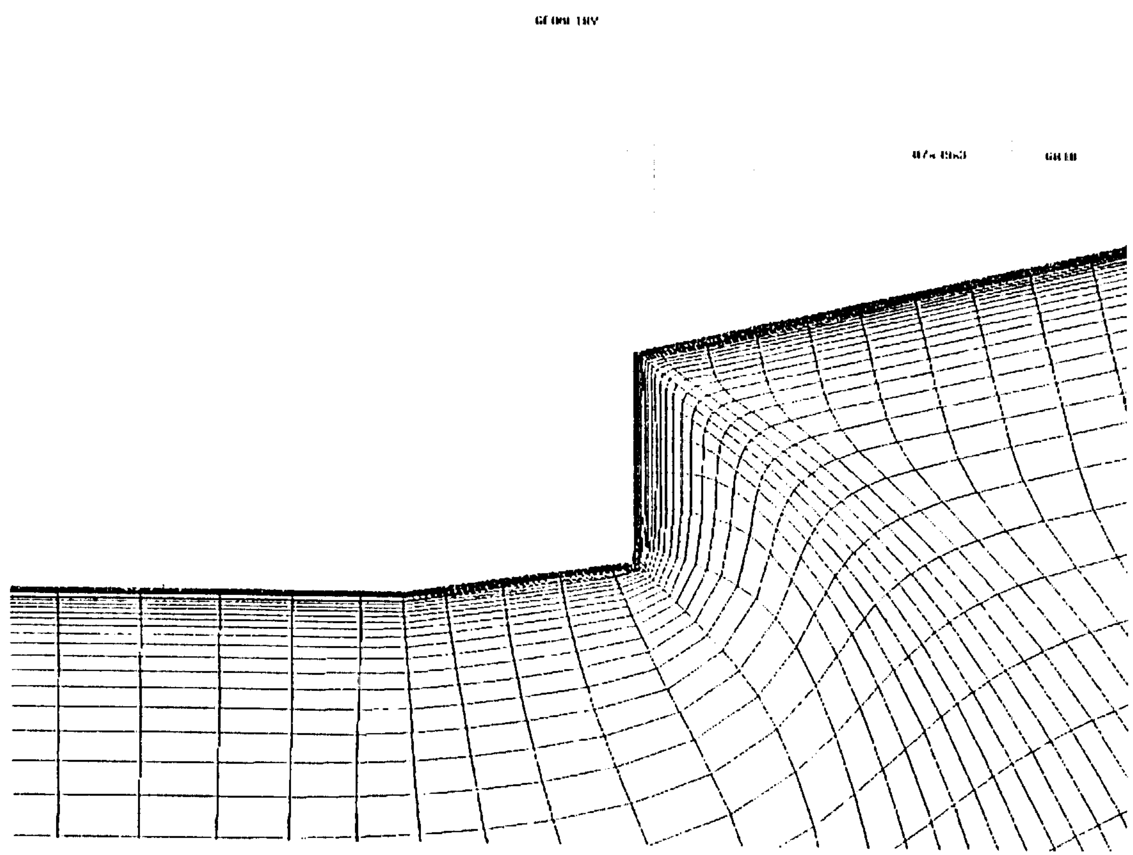
(Figure 4 (a))Grid for Model H calculations. a)Entire domain b)Close-up of area near engine exhaust





b)

Figure 4. Grid for Model II calculations. a)Entire domain b)Close-up of area near engine exhaust



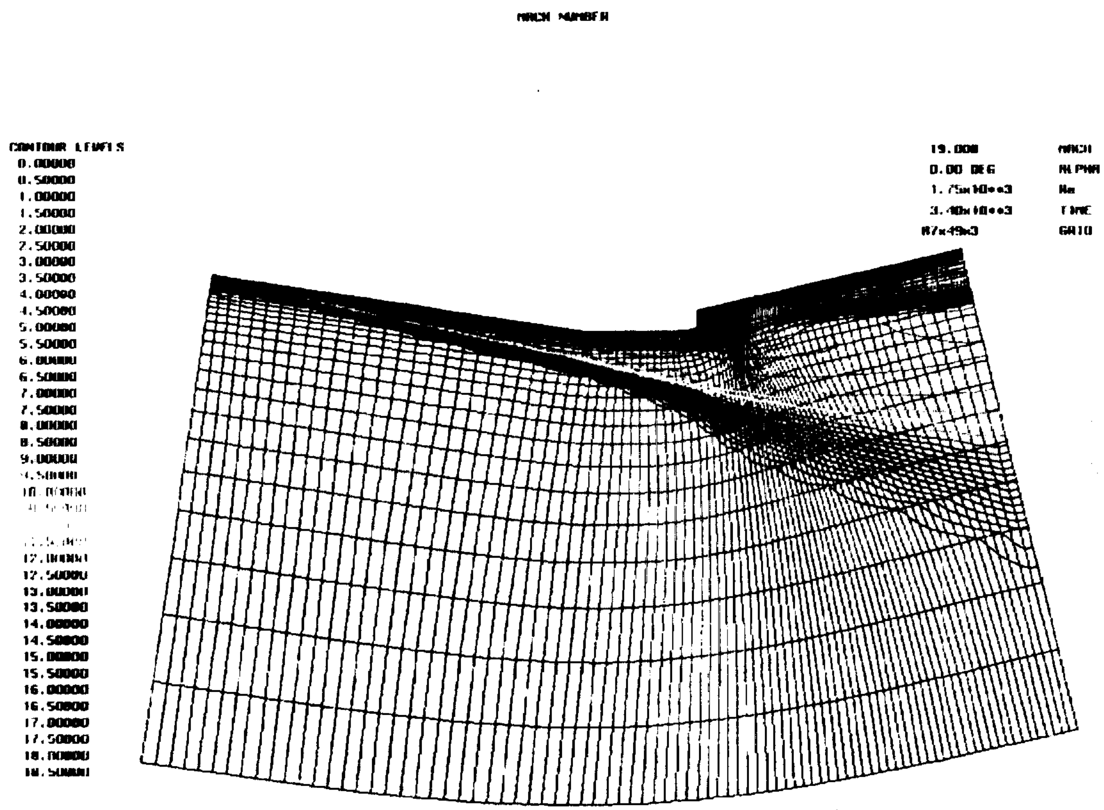


Figure 5. Mach contours at steady state over Model H configuration with Mach 19 (power off) starting conditions.

ORIGINAL PAGE
COLOR PHOTOGRAPH

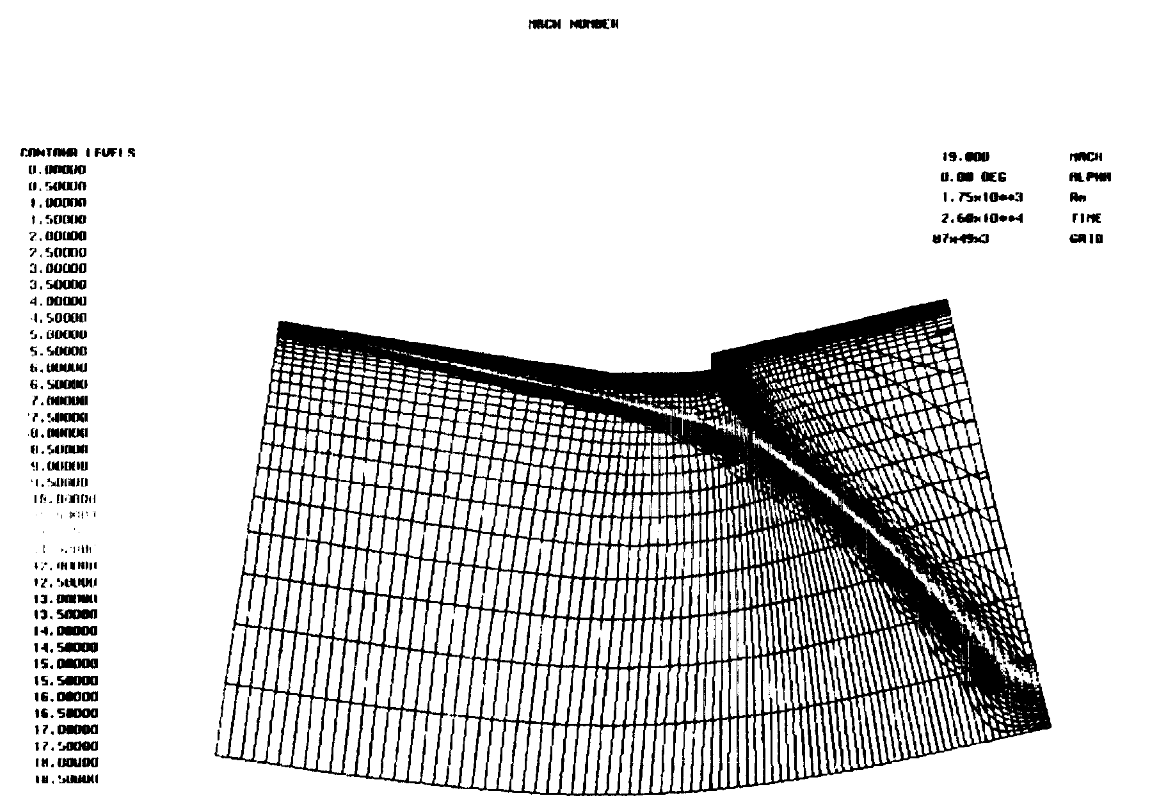


Figure 6. Mach contours at steady state over Model H configuration with Mach 19 and Mach 5 (power on) starting conditions.

ORIGINAL PAGE
COLOR PHOTOGRAPH

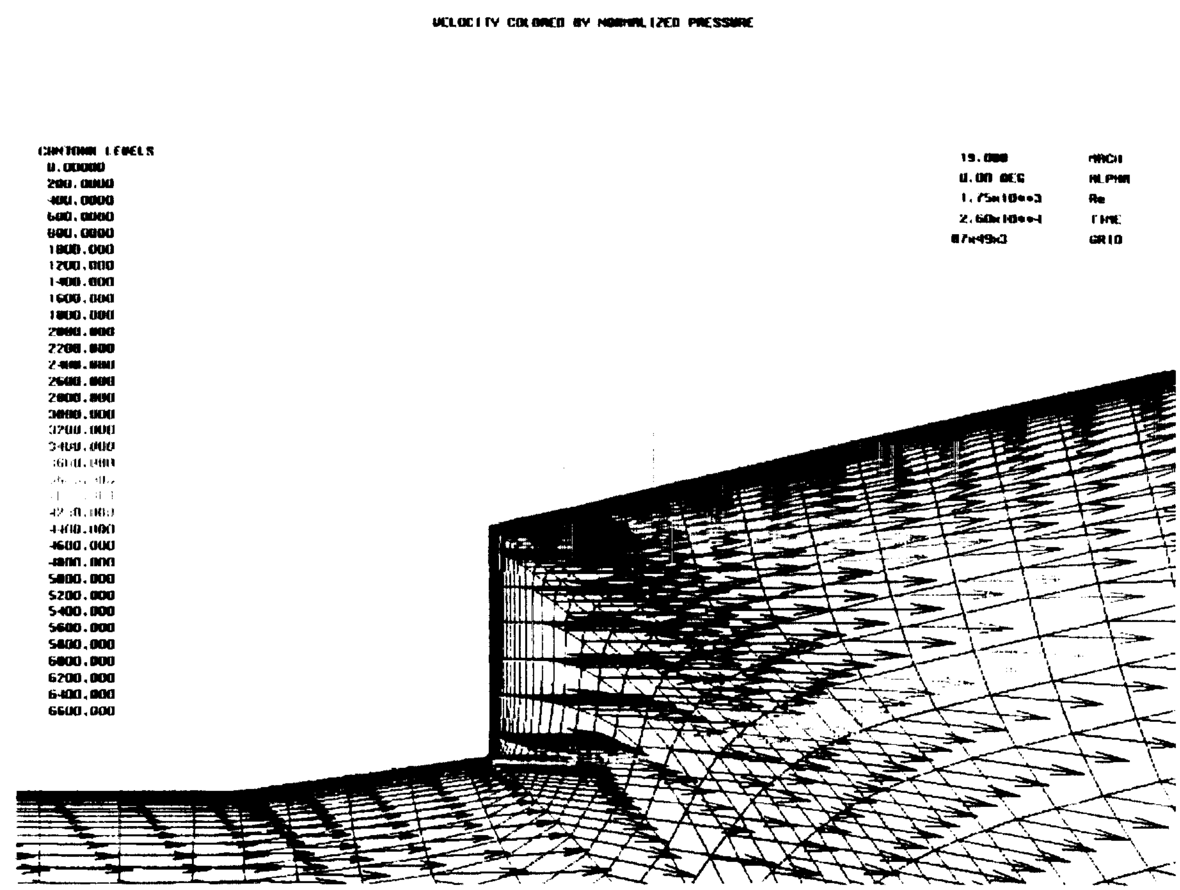


Figure 7. Velocity vectors near engine exhaust on Model H configuration with power on starting conditions at steady state.

ORIGINAL PAGE
COLOR PHOTOGRAPH

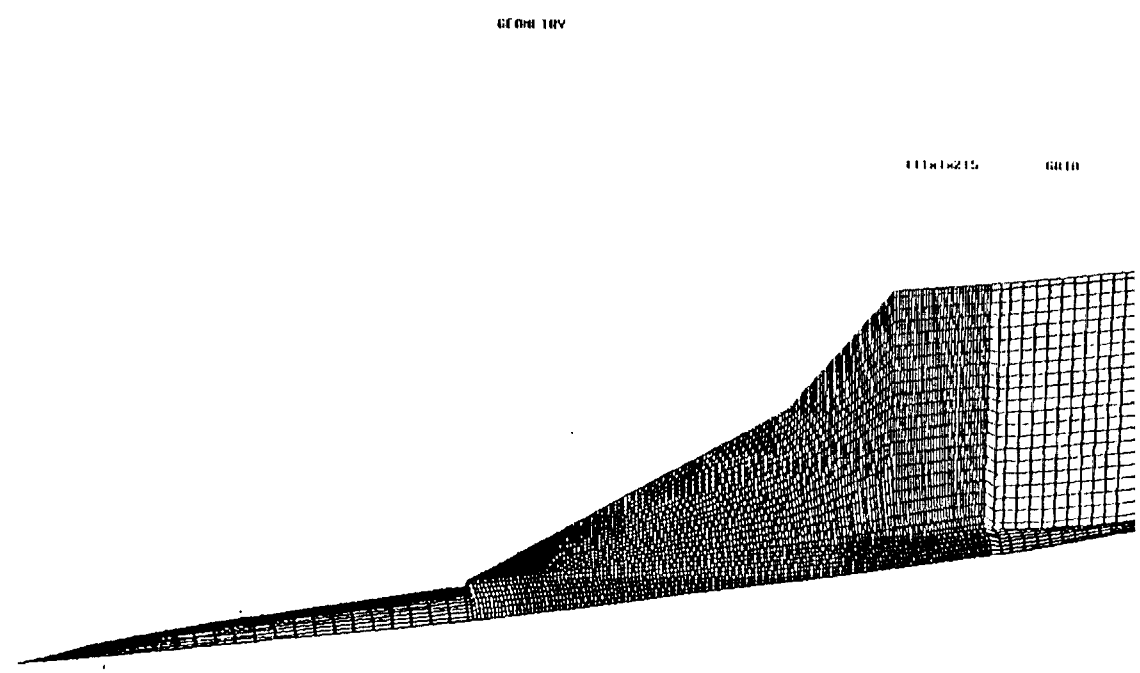


Figure 8. Grid with constant streamwise cuts used as input for first 1807 surface grid.

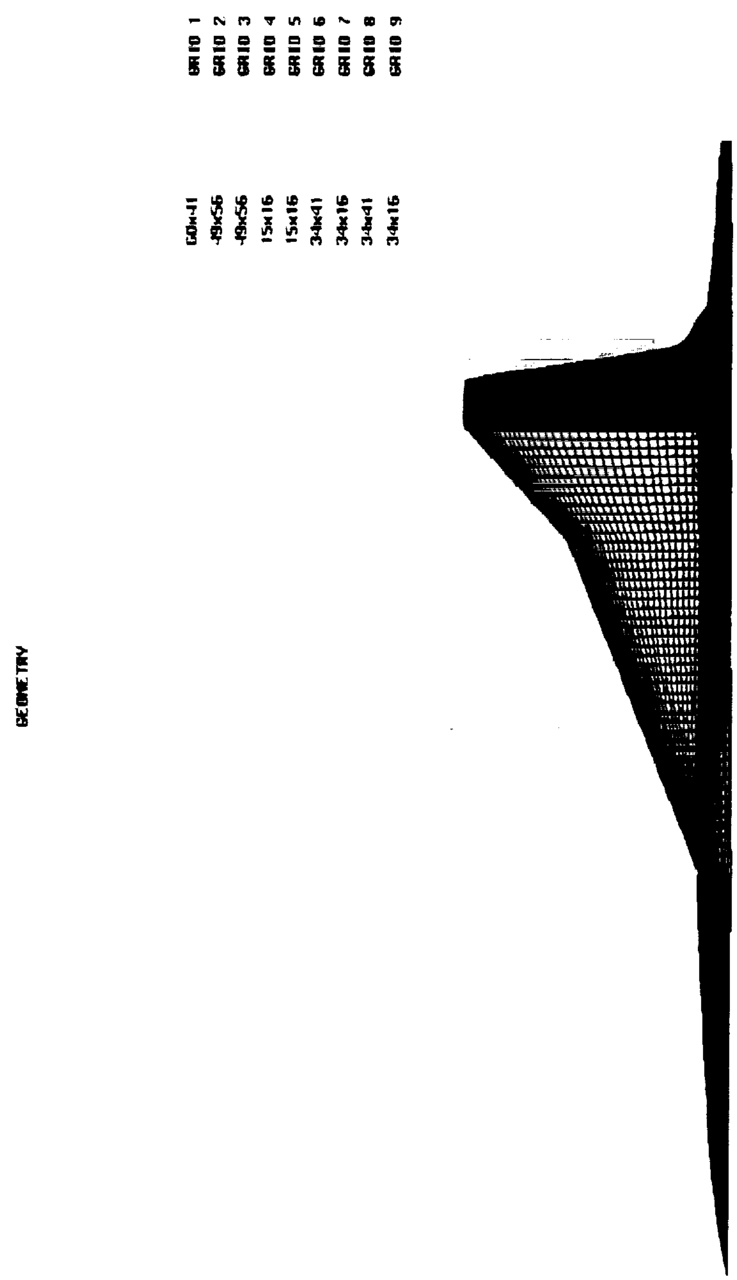


Figure 9. Four zone 1807 grid.

ORIGINAL PAGE
COLOR PHOTOGRAPH

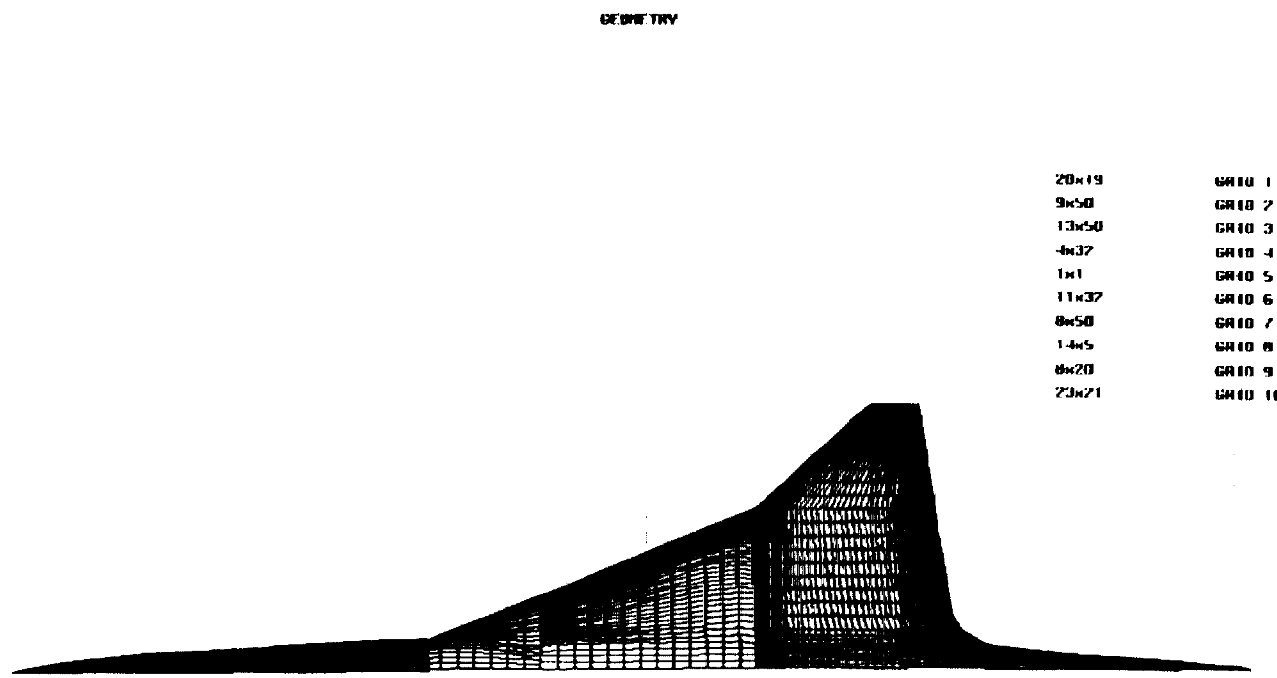


Figure 10. Seven zone 1807 grid which maintains sharp break between the subsonic and supersonic portions of the wing.

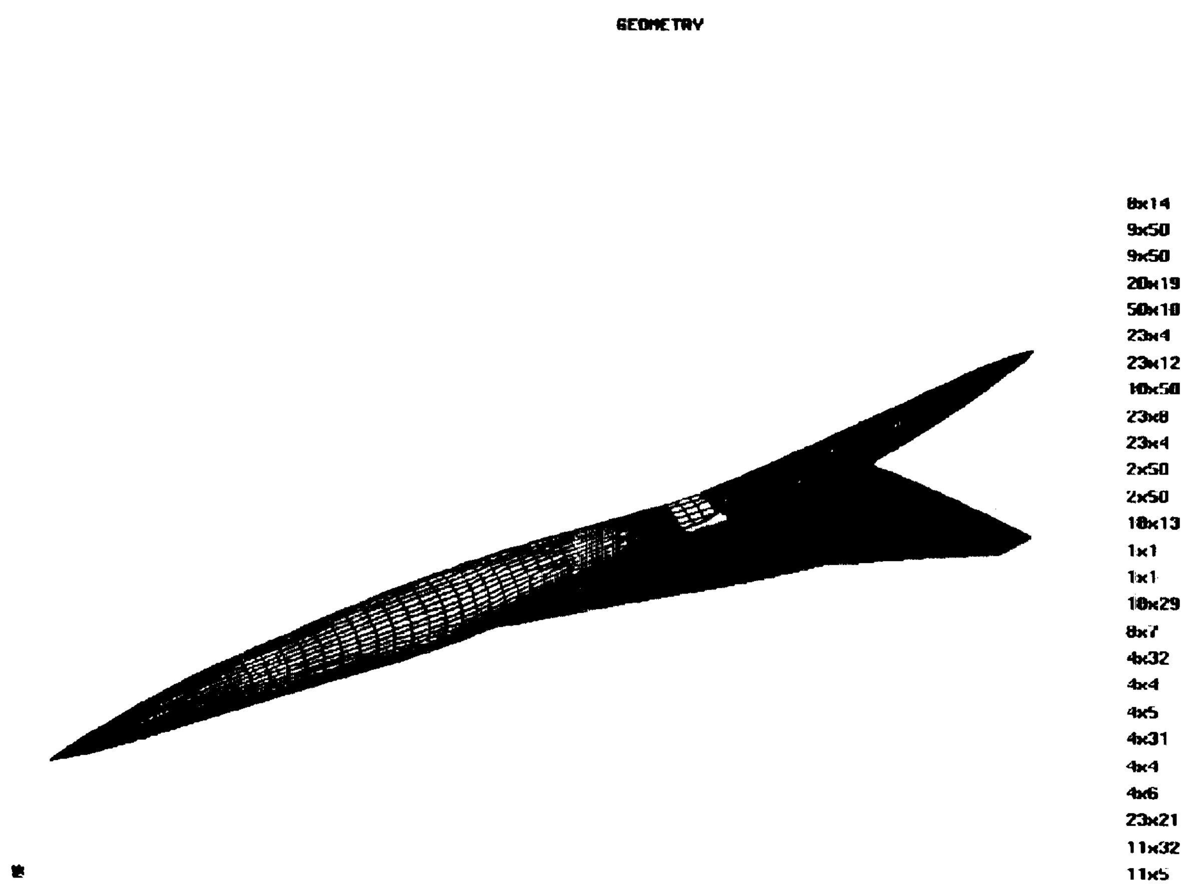


Figure 11 Intermediate 1807 grid containing 26 zones.

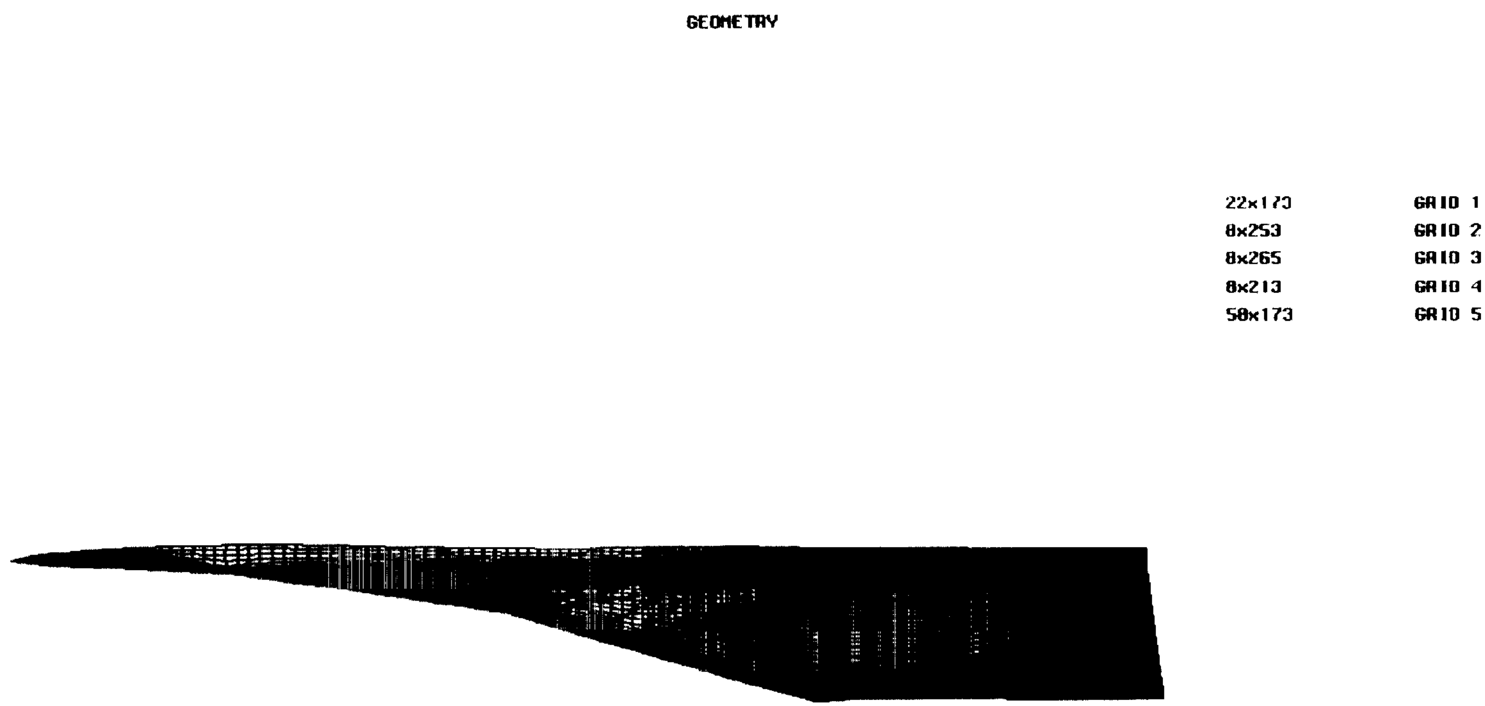


Figure 12 Hagland model surface grid with five zones.

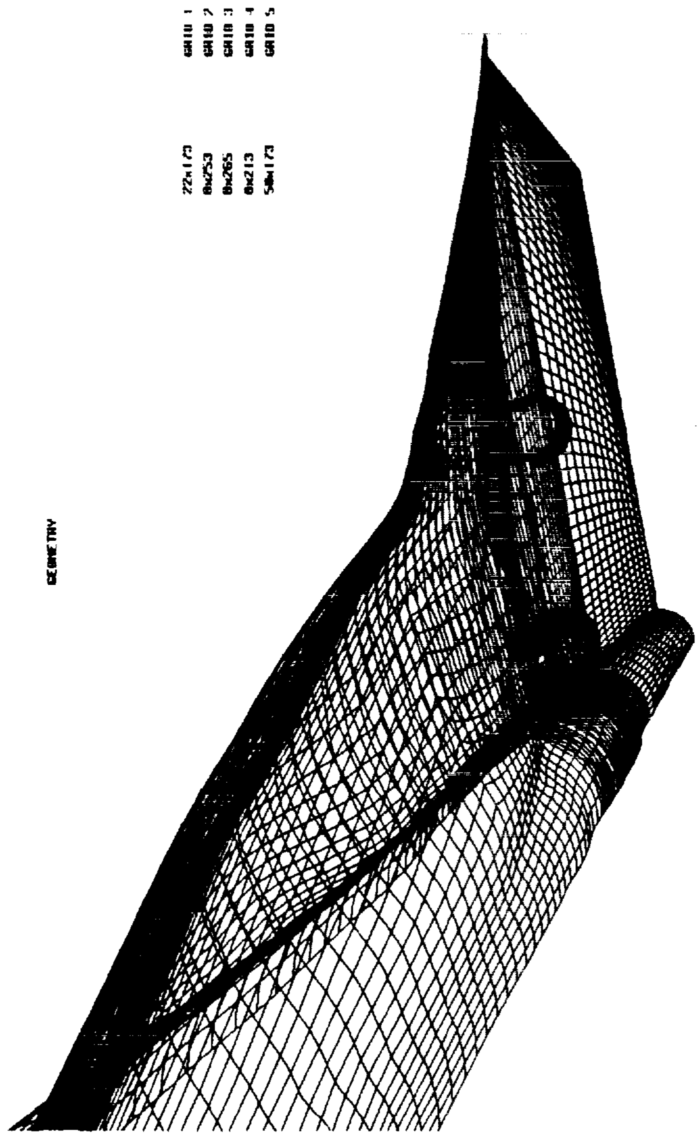


Figure 13 Underside of Hagland model surface grid showing nacelles.

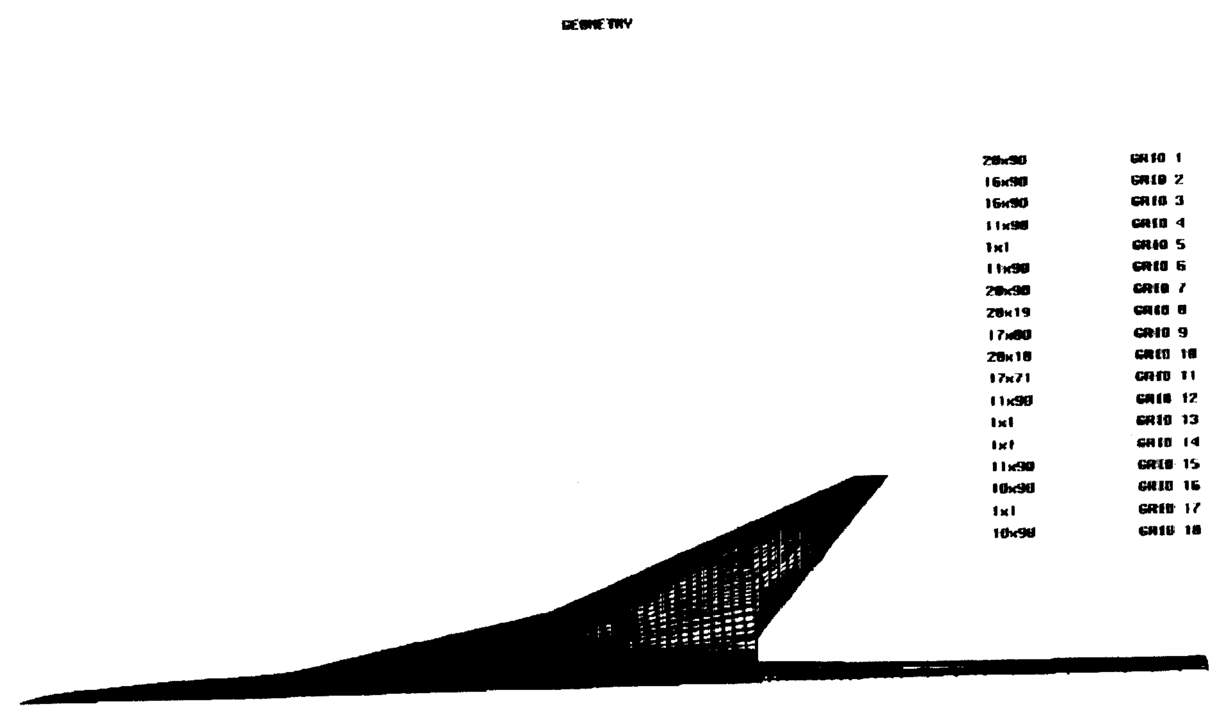


Figure 14 Hagland model grid created for use with GRIDGEN.

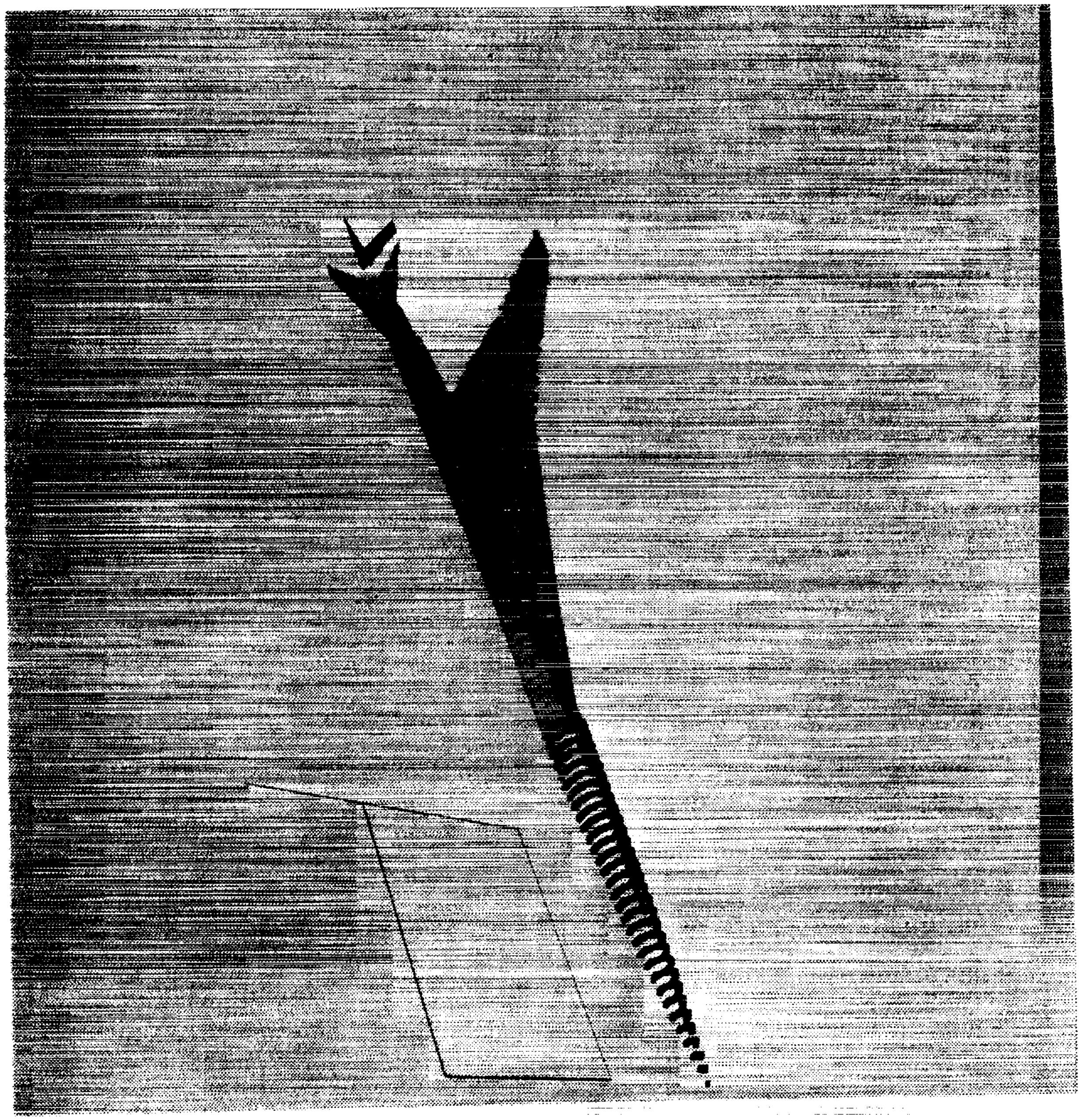


Figure 15 Incomplete Reference H model surface grid.

ORIGINAL PAGE
COLOR PHOTOGRAPH